A METHOD FOR MAKING PHOTOSENSITIVE FIBER SUITABLE FOR WAVELENGTH STABILIZATION GRATINGS

BACKGROUND OF THE INVENTION

Field of Invention

The present invention is generally directed to devices for optical communications, and more particularly to a method for making photosensitive fiber suitable for wavelength stabilization gratings.

Description of the Related Art

Wavelength stabilization gratings (also referred to as laser stabilization gratings) are weak fiber Bragg gratings used to lock a semiconductor laser to a particular emission wavelength. They are typically a few tenths of a nanometer wide and reflect a small percentage of the incident light, e.g. 1 to 10% of the guided power in the fiber.

Generally, wavelength stabilization gratings are fabricated using UV-induced index changes in a host fiber, such as a standard telecommunications type fiber. For 980-nm pump laser applications, these gratings are typically written in a 980-type fiber, such as Corning® CS-980™ fiber or Corning® Flexcor™ 1060 fiber. For 1480-nm pump laser applications, Raman amplifier pump applications, or signal laser applications, they may be fabricated in a fiber such as Corning® SMF-28™ fiber. Additionally, gratings may be written in a polarization-maintaining (PM) fiber such as Corning® PureMode™ PM Engineered fiber, PM 980 or PM 1550.

Hydrogen loading must be used with in standard telecommunications type fibers

to get the change in index required to make wavelength stabilization gratings. Hydrogen loading involves placing fibers in a chamber pressurized with hydrogen for extended periods of time at very high pressures, e.g., up to 12 days at 20-750 atm pressure. The loaded fibers are then stored at very cold (e.g. -80°C) temperatures to prevent outdiffusion of H_2. After grating formation, the gratings are thermally annealed to stabilize the index change, typically with a 24 hour anneal cycle at 140°C.

It would be preferable to remove the need for hydrogen loading. Hydrogen loading introduces several processing steps which may be preferable to avoid in manufacturing situations. This leads to increased manufacturing costs due to: increased processing steps, pressure chamber safety concerns, processing variability due to hydrogen out-diffusion, low temperature storage cost, and annealing requirements, among others. In addition, hydrogen loading is a long and expensive process. Therefore, it would be desirable to have a method of fabricating wavelength stabilization gratings which does not require hydrogen loading.

SUMMARY OF THE INVENTION

The present invention includes a method of making a preform for an enhanced photosensitive fiber comprising the steps of depositing successive layers of optical material inside a tube using modified chemical vapor deposition, and collapsing the successive layers of optical material in a reducing atmosphere with a positive pressure. Preferably, the positive pressure is between 0 and 1.0 torr. Additionally, the reducing atmosphere preferably comprises He.

The present invention also includes a method of making an enhanced photosensitive fiber comprising the steps of making a preform using modified chemical vapor deposition wherein the preform is collapsed in a reducing atmosphere with a positive pressure and drawing the preform into a fiber. Preferably, the positive pressure is between 0 torr and 1.0 torr. Additionally, the draw tension is preferably between 100 g and 250 g and the draw temperature is preferably between 1950°C and 2100°C.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features, aspects and advantages of the present invention will become apparent from the following description, appended claims and the exemplary embodiments shown in the drawings, which are briefly described below.

Figure 1 is a plot illustrating the effect of an oxygen deficient collapse on the index.

Figure 2 is a plot illustrating the effect of draw tension on the index.

Figure 3 is a plot illustrating the index as a function of exposure time.

Figure 4 is a plot illustrating the index as a function of exposure time.

Figure 5 is a cross section of a fiber Bragg grating according to a first embodiment of the invention.

Figure 6 is a cross section of a first embodiment of the invention illustrating the definition of the grating period Λ.

Figure 7 is a table summarizing the effect of various manufacturing parameters for GeO_2 doped MCVD fibers.

Figure 8 is a table summarizing the effect of various manufacturing parameters for GeO_2-B_2O_3-doped MCVD fibers.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present inventors have determined that optical fibers with enhanced photosensitivity can be manufactured by the modified chemical vapor deposition (MCVD) process, also known as the inside vapor (IV) deposition process, with careful control of various process parameters. These process parameters include the collapse condition and draw conditions, including draw temperature and tension. For example, optical fibers can be fabricated without hydrogen loading that exhibit changes in index up to approximately $1x10^{-3}$ when exposed to UV light. Thus, wavelength stabilization

gratings can be fabricated in these fibers more quickly and at a significantly lower cost than using prior art procedures.

The degree of photosensitivity of an optical fiber manufactured by the MCVD process is a function of the collapse conditions and the draw conditions. Figures 7 and 8 summarize the effects of various collapse conditions on GeO_2 doped MCVD fibers and GeO_2-B_2O_3 doped fibers, respectively. Each preform was collapsed in three successive stages. In most cases, the three collapse conditions were identical, e.g., the gas flow composition was held constant. In some cases, however, gas composition was changed after the first collapse, but held constant during the second and third collapse. Gases used include O_2, Cl_2, $GeCl_4$, He, and 2-propanol. The helium is used to produce an oxygen deficient collapse. Solid bullets indicate a gas was present during all three collapse stages, while numbers in parentheses indicate a gas was used only during that particular collapse stage. Where exact $GeCl_4$ flow rate is known, it is specified. Bullets indicate an unknown flow rate between 50-280 sccm $GeCl_4$. The temperature of the 2-propanol vessel was varied from room temperature up to 75°C, as indicated. The 2-propanol was used so that (1) hydrogen from 2-propanol might create the same effect as H_2 treatment and (2) carbon might create a reduced environment so that more oxygen deficient centers are created.

Figure 1 illustrates the effect of an oxygen deficient collapse on the index. The change in index was induced by exposing the fiber to a 240 nm UV laser operating at 10 Hz and a fluence of approximately 280 mJ/cm^2 for about 15 minutes. As can be seen in the figure, collapsing under oxygen deficient conditions results in significantly higher photosensitivity. The highest changes in index are produced when all three collapse stages are oxygen deficient (solid oval). However, having at least one oxygen deficient collapse stage also results in improved photosensitivity (dotted oval). The fibers with the lowest photosensitivity were fabricated by the outside vapor (OV) process. In the preferred embodiment of the invention, oxygen deficiency is achieved by using helium as the primary gas. However, other inert gases, such as argon and nitrogen may also be used.

In addition to collapsing with an oxygen deficiency, the inventors have determined that it is desirable to collapse under positive pressure. Preferably, the

collapse pressure should be between 0 and 1 torr. More preferably, the collapse pressure should be between 0 and 0.5 torr. Most preferably, the collapse pressure should be between 0.2 and 0.4 torr.

In the preferred embodiment of the invention, the preform is doped with Ge. However, the preform may also be co-doped with B_2O_3. This is especially advantageous for the fabrication of cladding mode suppression (CMS) fibers. CMS fibers are designed to have both a photosensitive core and a photosensitive cladding layer.

The effect of draw conditions on the photosensitivity is illustrated in Figure 2. An increase in draw tension increases the photosensitivity of the fiber. Further, a decrease in draw temperature increases the photosensitivity. This increase in photosensitivity was produced in both Ge-doped fibers and B-Ge-doped fibers. In the preferred embodiment of the invention, the preform is drawn with both a high tension and under low temperature. Preferably, the draw tension is between 100g and 250g. More preferably, the draw tension is between 150g and 200. The draw temperature is preferably between 1950°C and 2100°C. More preferably the draw temperature is between 1980°C and 2050°C. Most preferably, the draw temperature is between 1980°C and 1990°C.

Figures 3 and 4 are plots of the normalized modulated index of a assortment of GeO_2 doped fibers as a function of exposure time. The figures illustrate that both the degree of photosensitivity, as measured by the magnitude of the change in index, and the rate of change of the index is a function of the various process parameters. A combination of a preform collapsed with three oxygen deficient stages, high draw tension and low draw temperature produces the largest change in index and the fastest change in index. Collapse with oxygen, a low draw tension and a high draw temperature yields the smallest index and the slowest rate of change. By varying one or more of the parameters, intermediate degrees of photosensitivity and intermediate rates of change can be achieved.

Because the process parameters may be varied singly or in combination, it is possible to tailor and optimize the fiber response based on the desired end product. For example, it is possible to design a fiber which achieves an index suitable for laser

stabilization gratings with an exposure of less than 15 minutes. Further, a fiber may be fabricated which achieves an index suitable for laser stabilization gratings with an exposure of less than 5 minutes. It is also possible to achieve a suitable index in less than 1 minute or even within 30 seconds.

Figure 5 presents a cross section of a grating 1 in a fiber according to a first embodiment of the invention. The grating may be a fiber Bragg grating, a long period fiber grating, a laser stabilization grating or any other type of grating. The grating 1 has a core 3 comprising a material with enhanced photosensitivity. Example materials include, but are not limited to germanium doped silica and germanium and boron co-doped silica prepared from a preform collapsed in a reducing atmosphere with a positive pressure. Preferably, the core 3 is surrounded by a cladding layer 5 which has an index of refraction lower than the index of refraction of the core.

Within the core 3, is a region 7 which contains a regular array of periodic, permanent perturbations 13 of the index of refraction. The array of perturbations 13 form an optical grating having a grating period Λ. Figure 6 illustrates the grating period Λ. The array of perturbations 13 are formed by exposing the fiber to UV light pulses through a mask. Preferably, the light is supplied from a 240 nm frequency doubled 480 nm dye laser pumped by a 351 nm excimer laser, however other lasers may be used. For example, the following lasers may also be used: 248 nm KrF excimer, 193 nm ArF excimer, 244 nm continuous wavelength frequency doubled Ar and other UV lasers with wavelengths in the range of 190 nm to 350 nm.

Preferably, the laser stabilization gratings are made from fibers drawn with a large tension and at a low draw temperature. However, it is not necessary that the tension be large and the draw temperature be low. It is sufficient that the combination of processing parameters produce a fiber with a high enough photosensitivity such that exposure to UV radiation increases the index enough to form laser stabilization gratings without hydrogen loading the fiber.

The foregoing description of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention. The drawings

and description were chosen in order to explain the principles of the invention and its practical application. It is intended that the scope of the invention be defined by the claims appended hereto, and their equivalents.